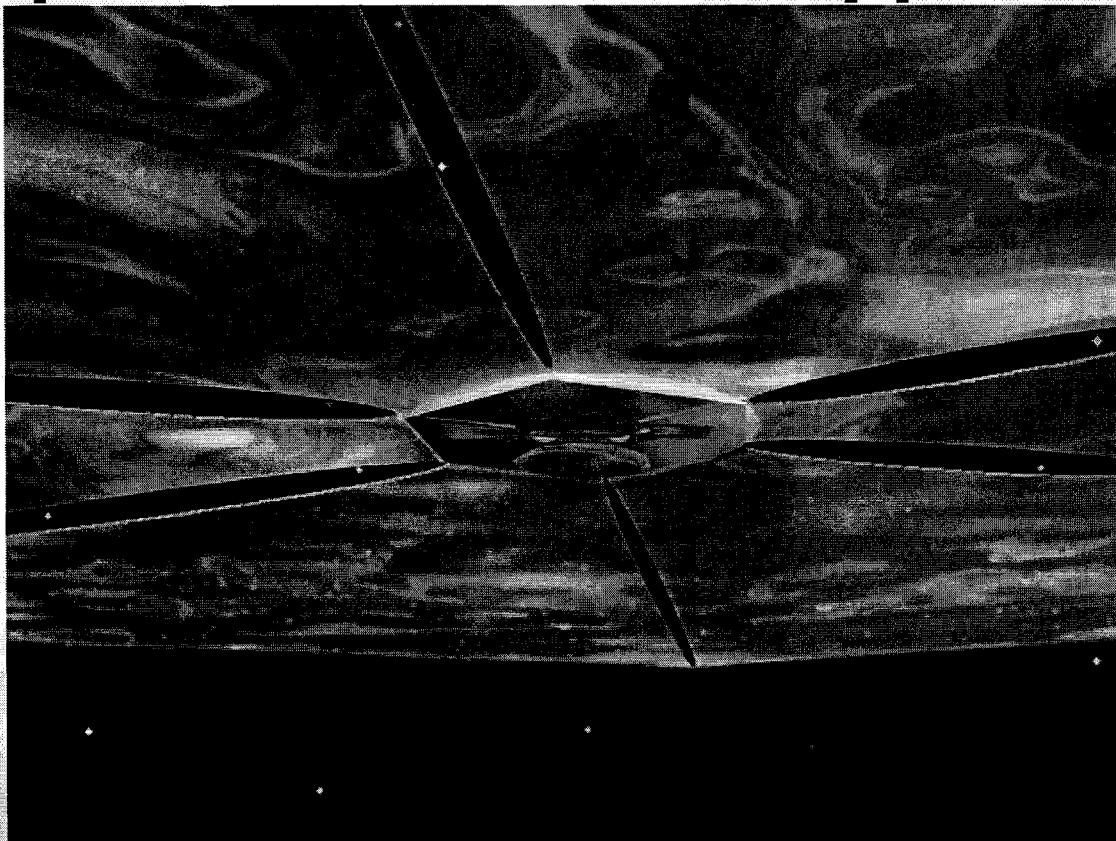


11th Advanced Space Propulsion Research Workshop
Session: Propellantless Propulsion

**Solar Sailing:
Perspective & Mission Applications**



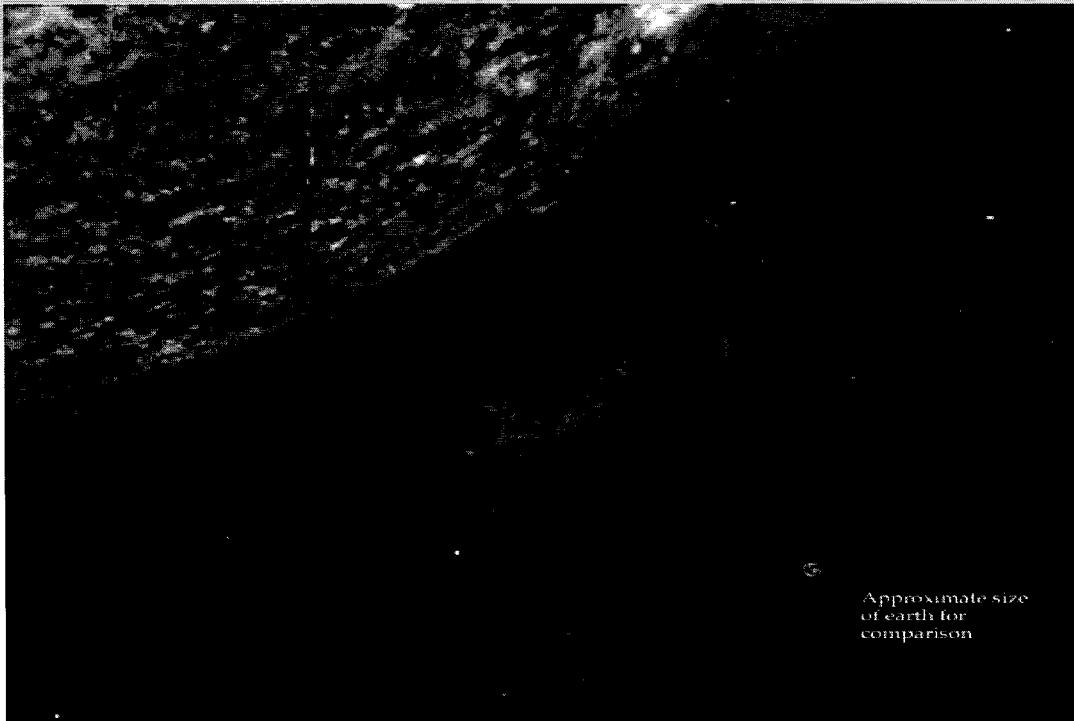
Richard A. Wallace
01 June 2000

1-06/01/00

Topics

- Solar Sailing?
- Sail Technology & the Customer
- Mission Applications

Solar Sailing?



Approximate size
of earth for
comparison

- Solar Radiation:
Photon Pressure, Solar Wind, Fields & Particles
- $F = Ma$ or $M_T a_C$
 $= (2 S_o A/c) \sin^2 \theta$ {at 1.0 AU}
where $(2 S_o/c) = 9.1265 \mu N/m^2$ or $10^{-6} kg/ms^2$

Solar Sailing History

(Ref.: C. Garner, 2000)

⌚ 19th Century

Early Physics

(Maxwell, Arrhenius, etc.)

⌚ 1900-1978

Early Concepts Leading to Mission/System Design

(Tsiolkovsky, Tsander, Wiley, Garwin, Cotter, Clark, Wright, etc.)

⌚ 1980s

Studies & Hardware

(World Space Foundation, Solar Sail Union of Japan, U3P, etc.)

⌚ 1988-1991

US Columbus Quincentennial Jubilee

("Solar Sail Regatta")

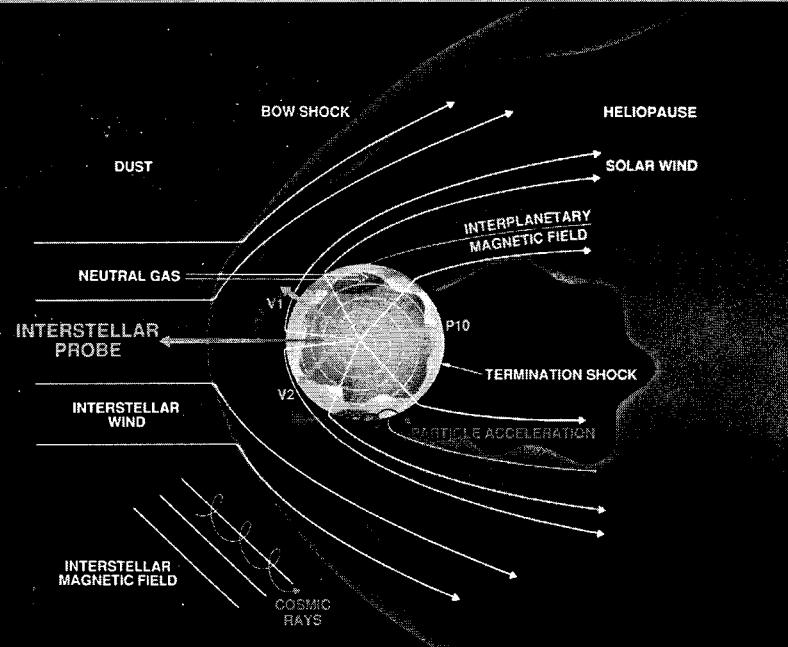
⌚ 1990s to Present

Significant Advances in Design, Hardware, & Advocacy

("Znamya", NASA M&M - NASA Codes S & R, DLR/NASA, ISP, NOAA, NMP, etc.)



Quest 3



Technology

- Solar Sail: $< 1 \text{ g/m}^2$, 200 m radius
- DSN 70m Subnet w/ Ka-band Uplink
- Next Generation ARPS
- Next Generation System On A Chip
- Ka-band S/C Components and Phased Array
- Hot-Gas Propulsion
- Micro-S/C Technology
- Low Mass/Power Instrumentation

Science Objectives

- Explore the interstellar medium and determine directly the properties of the interstellar gas, the interstellar magnetic field, low-energy cosmic rays, and interstellar dust
- Determine the structure and dynamics of the heliosphere, as an example of the interaction of a star with its environment
- Study, in situ, the structure of the solar wind termination shock, and the acceleration of pickup ions and other species
- Investigate the origin and distribution of solar-system matter beyond the orbit of Neptune

Mission Description (Mid-Term ~ 2010)

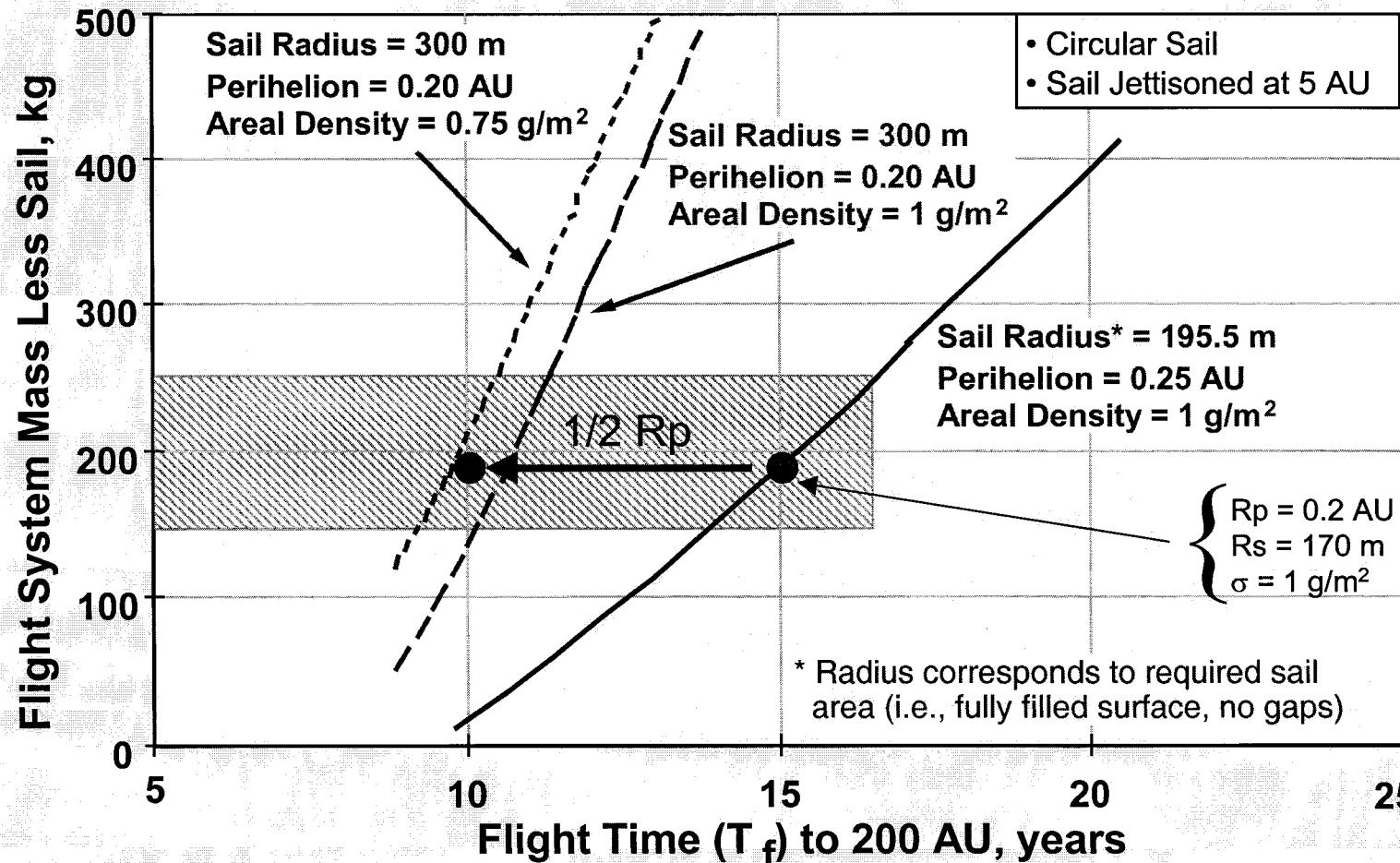
- Example Mission Design
 - Delta II 7425 Launch ($719 \text{ kg Cap.}, C_3 = 0 \text{ km}^2/\text{s}^2$)
 - Flight System Launch Mass: 564 kg
 - Solar Sail Trajectory Targeted for Nose of Heliosphere
 - * 0.25 AU Solar Pass, 200 AU in 15 yrs.
- Flight System Concept
 - "Flying Antenna" Design Implementation (191 kg)
 - Sized for 30 year Operations
 - Payload: Fields & Particles + Imaging

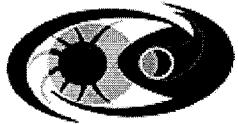
Measurement Strategy

- Measure, in situ, the properties and composition of interstellar plasma and neutrals, low energy cosmic rays, and interstellar dust
- Determine the structure and dynamics of the heliosphere with in situ measurements and global imaging
- Map the infrared emission of the zodiacal dust cloud, measure in situ the distribution of interplanetary dust, and determine the radial distribution of small Kuiper Belt objects

Technology & The Customer

Sail Performance Trade: T_f , S/C Mass, Perihelion with Sail Technology





SEC Roadmap Missions Enabled by Solar Sail

Time Frame	Mission	Potential Begin C/D Phase	Sail Radius (m)	Sail Areal Density (g/m ²)	Closest Solar Approach (AU)	Driving Requirements For Solar Sail (Time to Target, Years)
Mid Term	Solar Polar Imager **	'08 - '14	100	6	0.5	High Inclination (3-5 years)
	Space Weather Sentinel (SUB-L1)***	'08 - '14	100	6	0.95 (Hover)	Hovering (< 1 year)
	Particle Acceleration Solar Orbiter ***	'08 - '14	87	9	0.17	High Inclination (3-5 years)
	Interstellar Probe *	'08 - '14	200	1	0.25	High Speed (200 AU in 10-15 years)
Far Term	Solar Flotilla ***	'15 - '25	~500	1	0.2	High Inclination/?V of > 50 km/s (TBD)
	Inner Heliospheric Constellation ***	'15 - '25	~500	1	0.2	?V OF >50 km/s (TBD)
	Geospace System Response Imagers **	'15 - '25	600	0.5	1	Hovering (~5 years On Station)
	Outer Heliospheric Radio Imager *	'15 - '25	~300	0.25	0.25	High Speed (2-3 years)
	Interstellar Trailblazer *	'15 - '25	1,000	~0.1	~0.1	Very High Speed; ?V of ~300 km/s (2,000 AU in 30 years)

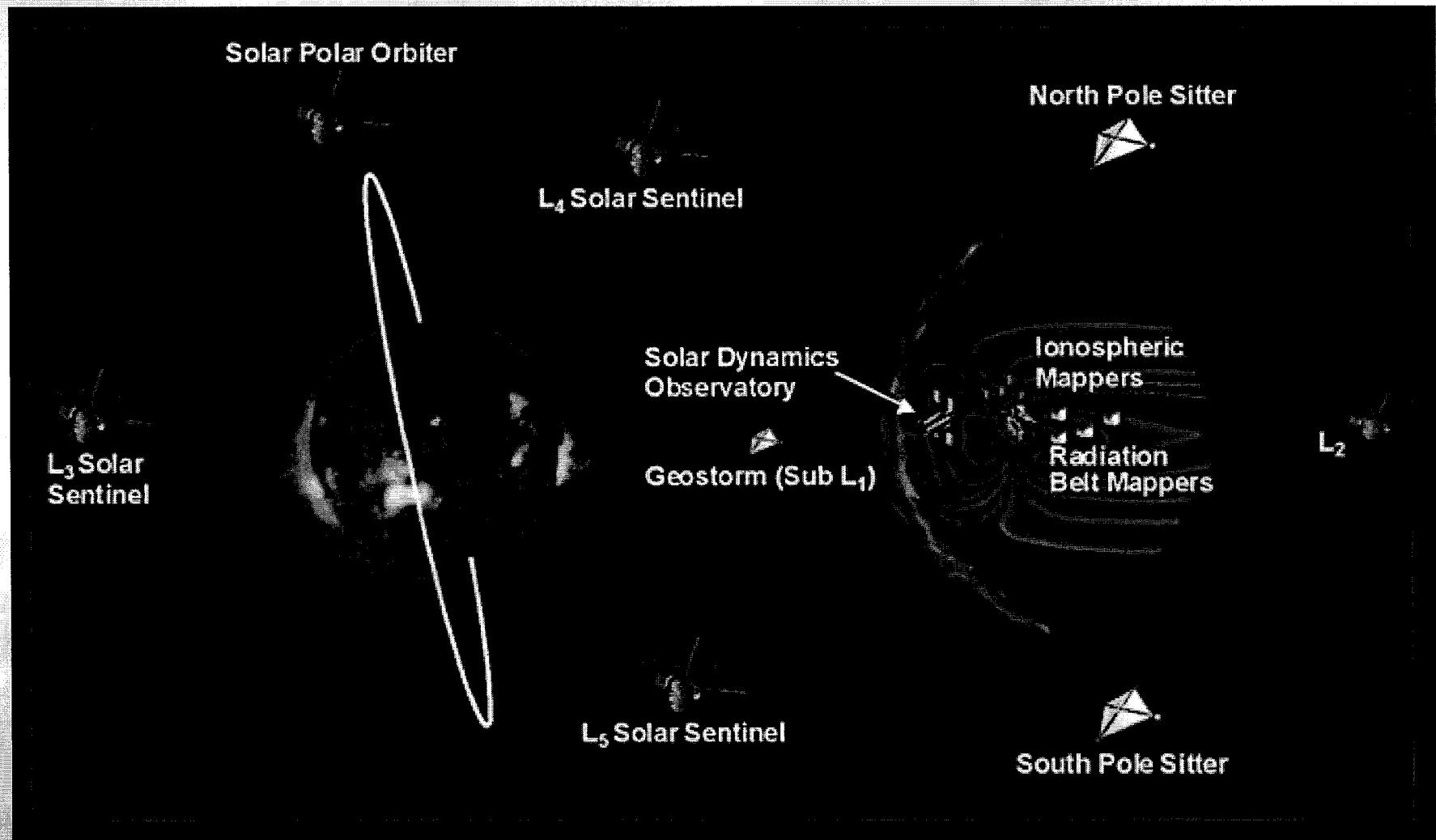
* New SEC Roadmap Quest #3 missions enabled by sail

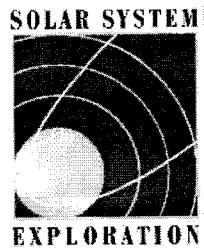
** Included in preliminary mission set of new "Living With A Star" (LWS) Initiative - **Sail-enabled version**

*** Potential for inclusion in LWS Initiative

Living With A Star Program

Space Weather Research Network - Element II





Sail Applicability: Planetary Missions

Mid-term ESS Roadmap missions currently baseline Solar Electric Propulsion (SEP), but flight time, payload mass, and end-to-end cost substantially benefit from solar sail availability.

Time Frame	Mission	Begin C/D Phase	Sail Radius (m)	Sail Areal Density (g/m ²)	Closest Solar Approach (AU)	Driving Requirements for Solar Sail (Time to Target, Years)
Mid Term	CNSR	2008	160	5	~1.0	Flight Time & Target
	Neptune Orbiter	2007	200	~ 5	~1.0	Flight Time (< 10 years)
	Titan Explorer	2007	200	~ 5	~1.0	Flight Time (< 5 years)
	Saturn Ring Observer	2007	200	~ 5	~1.0	Flight Time (< 5 years)
	Europa Lander	2007	200	~ 5	~1.0	Flight Time (< 2 years)
	Venus Sample Return	2007	100	~10	~0.7	Flight Time & Sample Size (< 5 years)
Far Term	Titan Sample Return	2015+	~ 300	~ 2	~1.0	Flight Time & Sample Size
	Triton Sample Return	2015+	~ 400	~ 2	~0.2	Flight Time & Sample Size